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Titanium Alloy Welding Using Middle Range Power Pulsed Wave Laser

Z. Mohid[1,a], Z. A. Rashid[1], A. Wagiman[1,b], M.N.H Rafai[1,c] and E.A. Rahim[1,d]

[1]Advanced Machining Research Group (AMRG),
Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia,
86400, Parit Raja, Batu Pahat, Johor, Malaysia.
[a]zazuli@uthm.edu.my, [b]abdulla@uthm.edu.my,
[c]nhakim@uthm.edu.my, [d]erween@uthm.edu.my

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Abstract. Laser welding are well reported to be excellent in precision parts joining with high reputations in external finishing. However, the process in obtaining the best processing parameters is not an easy task. In the case of pulse wave laser, the parameter setting constrained by the laser generator specification. Each laser parameters such as pulse width t_p, pulse repetition rate f_p and average laser power P_{avg} has relation which others. Increasing one parameter will directly decreases the maximum value of other parameters. The limited applicable combination and rage of processing parameters make it difficult to obtain the optimized processing parameters. This study is conducted to investigate the influence of each lasing parameters on the welding penetration capability. The range of applicable parameters for titanium alloy sheet metal has been successfully clarified

Introduction.

The parameters involved in laser welding can be divided into two categories, laser parameters and machine parameters. The most commonly discussed laser parameters are laser power or laser energy, pulse repetition rate, pulse width, laser beam size and focus position whilst machine parameters are such as travel speed, work piece geometry and irradiation angle.

The value of average power P_{avg}, pulse energy E, pulse repetition rate f_p, pulse width t_p and peak power P_{peak} are connected with one another. The relation between each parameter is shown in equation 1 and 2 where T is the time taken for each pulse cycle. Increasing one parameter will consequently lemmatize the other parameters applicable range. Each parameters give different effect to the welding characteristics.

$$E = P_{peak} \cdot t_p \tag{1}$$

$$P_{avg} = \frac{E}{T} = E \cdot f_p \tag{2}$$

In the case of welding penetration depth, peak power is the most influencing parameter. Penetration depth increases with peak power under constant pulse duration [1]. Increasing pulse repetition rate will effectively reduce the thickness of heat affected zone [2]. Increasing the pulse repetition rate will allows higher scanning speed with the same overlap area. This will consequently produce narrow welding width, thin heat affected zone and less underfill depth [3]. Laser power plays an important role in controlling the area of fusion [4]. It is crucially important to select a well balance value of laser power, pulse repetition rate and scanning speed to optimize welding quality. The combination of scanning speed and pulse energy could give significant influence on the type of welding; conduction or keyhole welding. The morphology and mechanical properties is largely influenced by the total energy input per unit area [5].

Experimental setup.

Laser head with focus distance and beam diameter of 160mm and 0.480mm was used to convey the laser beam on to the work piece material. The materials with 1.8mm of thickness were cut into 25mm x 5 mm and welded on a clamping device.

In the early study, the scanning parameters in Table 2 were determined based to the laser oscillator capacity shown in Table 1. The scanning speed and pulse repetition rate were determined with conditions that the overlap area must be more than 50%. The result of the early study has led to the new set of parameters. These parameters were used to focally analyze the influence of certain processing variables within a smaller range value to obtain the optimized processing parameters.

Table 1: Laser oscillator capacity

Items	Minimum Value	Maximum Values	Unit
Average Laser Power, *Pavg*	-	300	W
Peak Laser Power, P_{peak}	-	9	kW
Pulse Energy, E	-	56	J
Pulse Width, t_p	0.2	20	ms
Pulse Reptition Rate f_p	1	1000	Hz

Table 2 : Prelaminary study on scanning parameters for laser oscillator capacity confirmation

Scanning speed v(mm/min)	Pulse width t_p(ms)	Pulse repetition rate f_p(Hz)	Average laser power, P_{avg}(W)
300	0.2, 0.6, 1.0	100,500	10, 25, 50, 75, 125

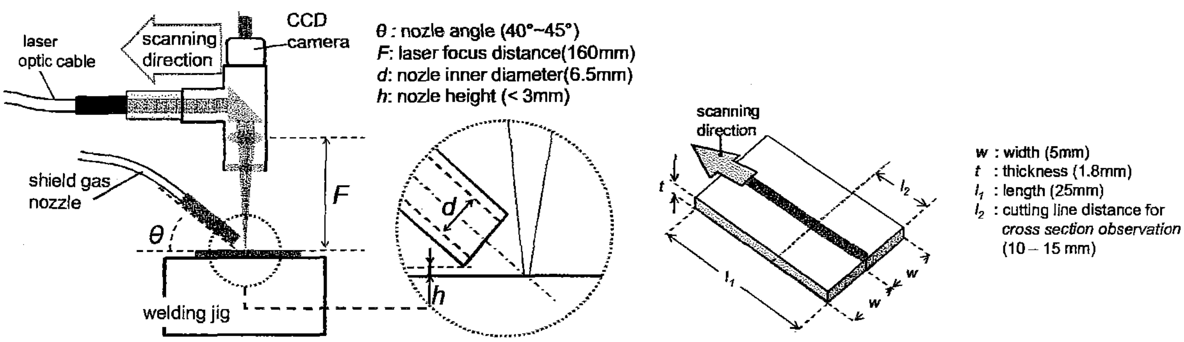

Figure 1: Experimental setup and work piece schematic diagram

Preliminary study has been done to clarify the range of parameters applicable for welding process of titanium alloy with thickness 1.8mm. Pulse repetition rate f_p were set lower than middle range (100Hz and less), to provide average laser power P_{avg} and pulse width t_p with larger modification range.

To obtain deep penetration welding beads, the influence of laser beam focus position has been studied. It was found that the penetration at 1.5mm underneath the work piece surface shows better result compared to the beam focusing on the top surface.

Further experiments were conducted to analyze the effect of processing parameters on the defect of free deep penetration welding as shown in Table 3. Laser scanning was performed with focus point of 1.5mm under the material top. Argon gas with flow rate 7l/min was delivered using 6.5mm inner diameter nozzle with approximately 45° tilted and the distance of 10mm from the scanning point.

Table 3: Processing parameters selected

Scanning speed v(mm/min)	Pulse width t_p(ms)	Pulse repetition rate f_p(Hz)	Average laser power, P_{avg}(W)	Energy E(J)
300	0.6, 0.8, 1.0	60, 80, 100	1.0, 1.15, 1.25	1.0, 1.15, 1.25

Results and discussion.

The study revealed that by employing the pulse width of 1.0ms, at least 0.5J is needed to initiate deep welding pool. Although increasing laser energy is effective to enhance penetration depth, there is a limit where cracks and sputtering problems become too obvious. Scanning using 100Hz of pulse repetition rate and 1.25J of laser energy, it needs to be done with pulse width 0.6ms and above to avoid sputtering problem. Figure 2 shows the effect of energy and pulse width on welding depth. It shows that the applicable pulse width is between 0.6 and 1.0ms while E is between 1.0 and 1.25J. In the case of f_p is 500Hz, the welding depth significantly decreases. By employing the lower f_p of 100Hz subsequently deeper welding depth can be obtained.

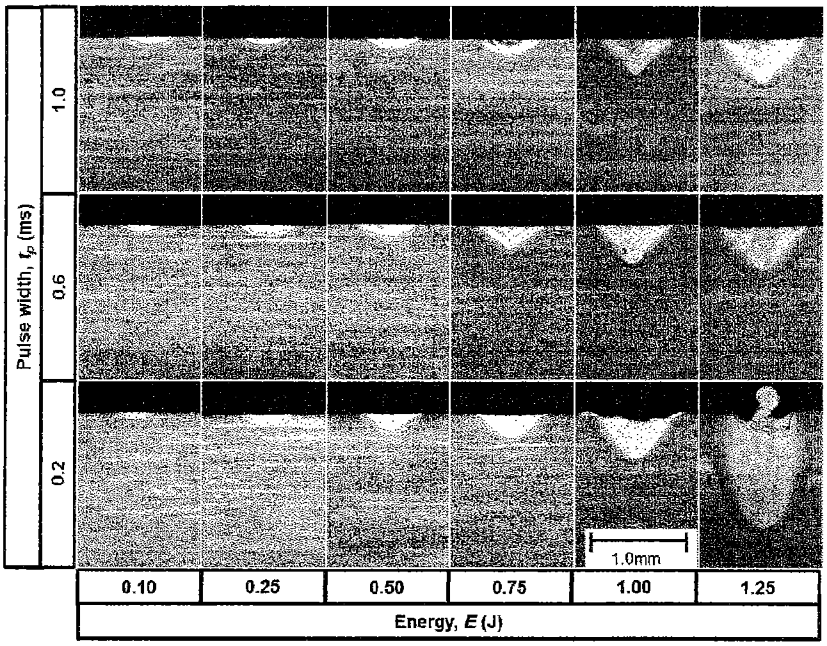

Figure 2 : Melted zone cross section view under different energy and pulse repetition rate.

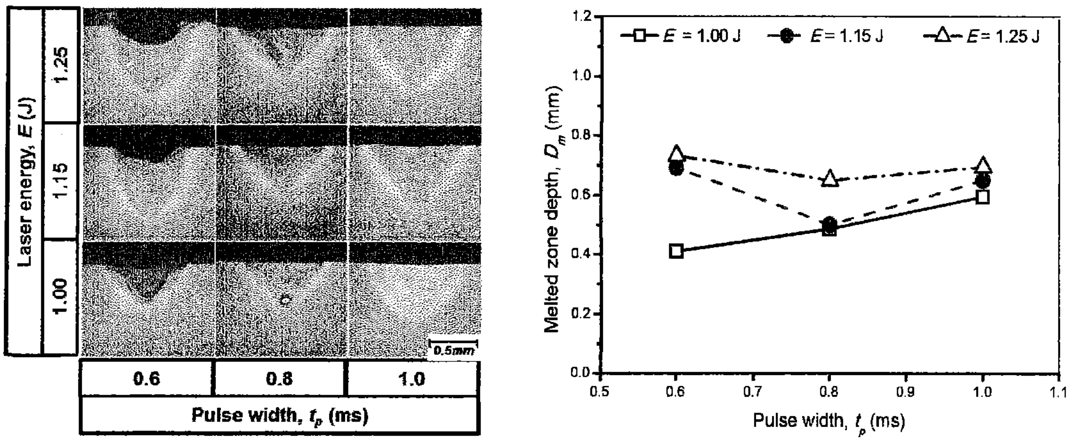

Figure 3: Comparison of melted zone depth created under 100Hz pulse repetition rate and 300mm/min scanning speed

Further experiment was conducted using the parameters listed in Table 3. In general, pulse repetition rate ranging between 60Hz to 100Hz was insignificant in the changes of melted zone width and depth. In the case of pulse duration 0.6ms, melted zone depth increases steeply with the increase of pulse repetition rate. However the maximum melted zone depth was approximately equal to the one crated using 0.8ms and 1.0ms of pulse width.

Under 1.25J laser energy, scanning speed of 300mm/min and pulse repetition rate of 100Hz, the melted zone depth on blank titanium alloy sheet reaches 0.7mm. Cross sectional views of the specimens revealed that the range of parameters was thoroughly applicable in actual welding. Although lower pulse width could create deeper and sharp melted zone, the top surface conditions were unfavorable for sputtering and obvious overlap melted metal layers can be seen.

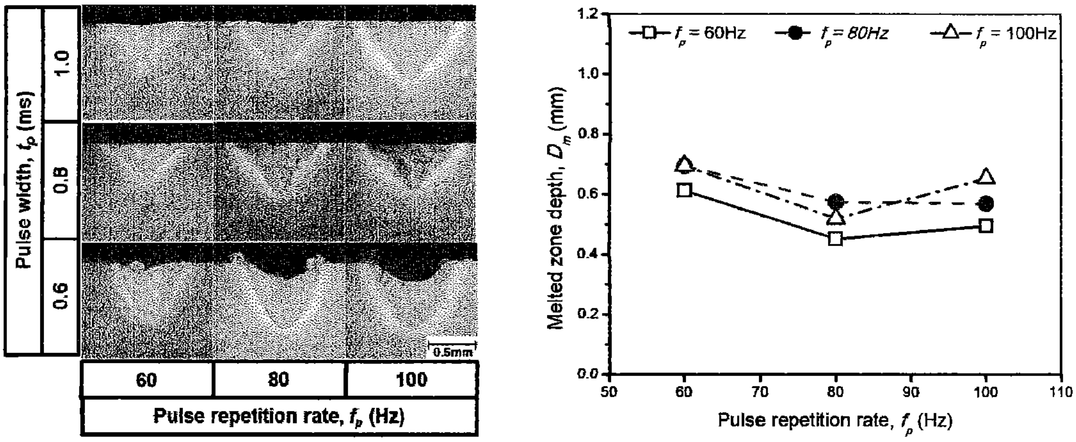

Figure 4: Comparison of melted zone depth created under 1.25J laser energy and 300mm/min scanning speed

Figure 4 shows the influence of different pulse repetition rate and pulse width on the melted zone geometry. The cross sectional of melted zones indicate that the pulse width needs to be larger in order to obtain clean welding beads. The peak power at pulse width of 0.6ms is assumed to be too high which initiate high pressure generation during each irradiation. By comparing the depth between three different pulse width, 0.8ms created shallow the melted zone. It is suggested that the difference in keyhole formation efficiency under differences peak power contributed to the variation of melted zone depth. Smaller value of depth to width ratio of the melted zone indicates that the heat energy has induced into the material and spread equally in radial direction under bigger pulse width. Reducing the pulse width under the same energy will increase the peak power. This will consequently generates higher expansion pressure in the melted area. Therefore, it creates the keyhole which could increase the laser absorption rate. However the time of thermal energy to be conducted into the material becomes shorter and it chilled before the next laser spark. The increment of laser absorption rate and reduction of thermal energy conduction time has contributed to shallow melted zone under 0.8ms pulse width.

Conclusions

Investigation on the influence of each parameter has been done started in broad range value to see the melted zone changes tendency. Form the result, focus has been given to a small range of parameters seems to be applicable. In the case of middle range powered Nd YAG laser, it can be concluded as bellow.

1. Scanning using 100Hz or less under 300mm/min scanning speed could only produce melted zone with maximum depth not more than 0.8mm on Ti6Al4V.
2. Using larger pulse width is able to reduce the risk of sputtering problem. At least 1.0ms is needed for clean and flat welding line creation.
3. Under a constant pulse width, increasing pulse repetition rate could moderately increase the melted zone depth.
4. To increase the melted zone depth, other parameters such as scanning speed need to be considered to enable larger energy induction in a specific unit area.

Acknowledgement

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